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Effects of alternate drip irrigation and superabsorbent polymers on growth and water use of young coffee tree

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Abstract

To obtain optimal irrigation management for young coffee tree, the effects of alternate drip irrigation (ADI) and superabsorbent polymers on physiology, growth, dry mass accumulation and water use on one-year old *Coffea arabica* L. tree were investigated. This experiment had three drip irrigation methods, i.e., conventional drip irrigation (CDI), alternate drip irrigation (ADI) and fixed drip irrigation (FDI), and two levels of superabsorbent polymers, i.e., no superabsorbent polymers (NSAP) and added superabsorbent polymers (SAP). Compared to CDI, ADI saved irrigation water by 32.1% and increased water use efficiency (WUE) by 29.9%. SAP increased root-shoot ratio, total dry mass and WUE by 20.3, 24.9 and 33.0%, respectively, when compared to NSAP. Compared to CDI with NSAP treatment, ADI with SAP treatment increased total dry mass by 13.8% and saved irrigation water by 34.4%, thus increased WUE by 73.4%, and it increased root activity, the contents of chlorophyll and soluble sugar in leaves by 162.4, 38.0 and 8.5%, but reduced the contents of proline and malondialdehyde in leaves by 7.2 and 9.7%, respectively. Thus, alternate drip irrigation with superabsorbent polymers increased the growth and WUE of young *Coffea arabica* L. tree and was optimal irrigation management for young coffee tree.

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Introduction

Partial root-zone irrigation, including alternate and fixed or partial root-zone drying, is a water-saving irrigation technique (Kang *et al.*, 2002; Loveys *et al.*, 2000) and may improve water use efficiency of crop production without much yield reduction (Kang and Zhang, 2004; Li *et al.*, 2007;Tang *et al.*, 2005). Previous studies indicated that alternate PRI reduces transpiration rate significantly and maintains higher level of photosynthesis rate, which leads to increase in water use efficiency of leaves (Kang and Zhang, 2004), and also reduces excessive vegetative growth of crops (Graterol *et al.,* 1993). Several studies about the effect of partial root zone irrigation on maize, cotton, tomato, tobacco, lily (*Lilium spp*.), grape, appleand olive are available.

Superabsorbent polymers can absorb water up to hundreds times more water of its weight, and its holding water can be absorbed by plants (Orikiriza *et al.*, 2009). Applied superabsorbent polymers can improve physical property of soil and water-holding capacity (El-Amir *et al.*, 1993), increase growth and yield (Yazdani *et al.*, 2007), but reduce crop irrigation demand (Taylor and Halfacre, 1986). However, superabsorbent polymers can fully conserve water and increase crop yield only when proper irrigation quota is applied (Zhang *et al.*, 2012).

Drought decreases leaf stomatal conductance significantly, but it does not affect chlorophyll fluorescence parameters of mature robusta coffee leaves significantly (Sidney *et al.*, 2006). Mild water stress reduces leaf photosynthetic rate, transpiration rate, soluble protein, chlorophyll and carotenoid, contents stomata opening and water potential, however increases peroxidase activity, proline and malondialdehyde content and cell permeability in coffee tree (Dong and Wang, 1996;Pinheiro *et al.,* 2004). Irrigation in hot dry season increases leaf photosynthetic rate and flower and fruit numbers of coffee (Dong and Wang, 1996), and advances florescence (Masarirambi *et al.*, 2009), but frequent irrigation inhibits buds blooming (Crisosto *et al.*, 1992). But rewatering after water deficit can stimulate blooming of buds and shorten harvesting time (Crisosto *et al.*, 1992). In addition, there is greater water consumption of coffee during growth period (Dhaeze *et al.*, 2005), but there are few studies about water-saving irrigation for coffee tree.

Partial root-zone irrigation and superabsorbent polymers are two kinds of water-saving technique, so the objectives of the present study was to investigate the effects of alternate drip irrigation and superabsorbent polymers on physiology, growth, dry mass accumulation and water use of young *Coffea arabica* L. tree, so as to find optimal irrigation management for young *Coffea arabica* tree.

Materials and Methods

Experimental site and materials : A pot experiment was carried out in a greenhouse in Faculty of Modern Agricultural Engineering, Kunming University of Science and Technology in Kunming, Yunnan, China, from April to December in 2013 under controlled conditions. Experimental soil was dry red (Ferric Acrisol) and had a field capacity of 23.4% (mass by mass), soil organic matter content of 5.05 g kg^{-1}, total N content of 0.87 g kg^{-1}, total P content of 0.68 g kg^{-1} and total K content of 13.9 g kg^{-1}. The clay, silt and sand content were 11.7%, 21.4% and 66.8%, respectively. One-year-old *Coffea arabica* (Catimor P7963) plants were used as experimental tree from Baoshan, Yunnan, China.

Experimental method : Pot experiment had three drip irrigation methods and two superabsorbent polymers levels. This experimental plan yielded six treatments (i.e. 3×2), and each treatment was replicated four times (Table 1), in total 24 pots. Three drip irrigation methods included conventional drip irrigation (both sides of the pot irrigated simultaneously at each watering), alternate drip irrigation (alternate watering on both sides of the pot at each watering) and fixed drip irrigation (fixed watering on one side of the pot at each watering). The drip irrigation system was used by a device of tree infusion bag (water bag volume of 2.0 l, two control valves in each water delivery hose and dripper flow rate of 0.6 l hr^{-1}). Dripper was inserted 2 cm below soil surface when watering, and the control valve was switched to implement different drip irrigation methods. As a new material, superabsorbent polymers can absorb water hundreds tunes more of its own weight and store water in soil, and then release water slowly according to plants requirement. Two superabsorbent polymers levels included added superabsorbent polymers (SAP, 1 kg m^{-3}) and no superabsorbent polymers (NSAP). Superabsorbent polymers are white granular power (particle diameter was 0.4-1.0 mm) of polyacrylatic acid, colorless gel after absorbing water (Xitao Chemistry Inc., Beijing, China) and were evenly mixed with soil at the commencement of the experiment. All the treatments were applied with 3 g kg^{-1} soil of soluble fertilizer (total N content of 10%, P_2O_5 content of 30% and K_2O content of 20%). Fertilizer was applied twice to the pots on May 26 and August 26.

One-year old *Coffea arabica* trees were transplanted in the plastic buckets (30 cm in diameter at the top edge, 22.5 cm in diameter at the bottom and 30 cm in depth, 16.3 l in volume). Six holes of 0.5 cm diameter were uniformly punched at the bottom to provide better aeration. Inside of all the buckets was evenly separated into two compartments with plastic sheets sealed at the middle, so that water exchange among the containers was prevented. Each sub-part was filled with 7 kg air-dry soil after sieving 2 mm with bulk density of 1.2 kg m^{-3}, soil surface was covered with 0.5 cm thick vermiculite to prevent soil hardening from the irrigation. Each bucket had one young *Coffea arabica* tree and soil water content in all the buckets were kept to field capacity after transplanting. At 54 days after transplanting, 24 one-year-old *Coffea arabica* trees with relatively uniform growth were selected for drip irrigation treatment on June 4. Irrigation was controlled by weighing method when soil water content reduced to or near to the lower limit of soil water content. Soil water contents in all the pots were kept at 70 to 85% field capacity before irrigation treatment, and it was kept at 70 to 85% field capacity in conventional drip irrigation after irrigation treatment. Alternate drip irrigation and fixed drip irrigation had same irrigation time with conventional drip irrigation and 2/3 of irrigation quota in conventional drip irrigation. There was no leakage and runoff in this experiment. Pot location was changed every 10 day to prevent systematic errors from the environment. Experiment period of 185 days after irrigation treatment.

Plant sampling and measurements : Physiological indices except for root activity of young *Coffea arabica* tree were measured at vigorous growth stage (Kong *et al.,* 2006). The contents of water, chlorophyll (Chl), proline (Pro), malondialdehyde (MDA) and soluble sugar (SS) in the first fully expanded leaves from canopy top were measured. Leaf

Table 1 : Experimental design for pot experiment

Treatment	Drip irrigation method	Superabsorbent polymers level
T1	Alternate drip irrigation (ADI)	SAP
T2		NSAP
T3	Fixed drip irrigation (FDI)	SAP
T4		NSAP
T5	Conventional drip irrigation (CDI)	SAP
CK		NSAP

SAP and NSAP represent added superabsorbent polymers and no superabsorbent polymers

water content was measured by weighing method, Chl content by ethanol extraction colorimetry, Pro content by acidity ninhydrin, MDA content by thiobarbituric acid colorimetry (TBA) and SS content by anthronecolorimetry. Root activity was measured by TTC reduction after fresh root samples were obtained (Gao *et al.,* 2006).

Morphological indices and different organ masses of young *Coffea arabica* tree were measured at the end of the experiment. Plant height and shoot length were measured by mm ruler, stem diameter by calipers and leaf area by paper weighing-conversion method. Fresh root samples were obtained from soil by repeated washing in fine sieve. Different organs were separately harvested for their dry mass. Plant material was firstly dried at 105 ºC for 30 min, and then dried at 80 ºC to constant weight. Root-shoot ratio was defined as the ratio of root dry mass to canopy dry mass, and specific leaf area was defined as the amount of leaf area per unit leaf dry mass. Total water consumption was calculated by water balance equation, and water use efficiency was defined as the amount of total dry mass per unit water use.

Statistical analysis : All the treatment means were compared for any significant differences by Duncan's multiple range tests at significant level of $P_{0.05}$ using SAS for Windows software package.

Results and Discussion

As shown in Table 2, compared to conventional drip irrigation, alternate drip irrigation increased the contents of chlorophyll, proline, malondialdehyde and soluble sugar in leaves by 27.1, 69.6, 13.3 and 88.0, and fixed drip irrigation by 21.1, 204.6, 74.6 and 164.2%, respectively. alternate drip irrigation increased root activity by 95.5% but fixed drip irrigation reduced root activity by 27.9%. In addition, both alternate drip irrigation and fixed drip irrigation did not affect leaf water content significantly. Compared to no superabsorbent polymers (NSAP), added superabsorbent polymers (SAP) increased leaf Chl content and root activity by 9.0 and 39.8%, but reduced the contents of leaf Pro, MDA and SS by 46.0, 29.4 and 45.7%, respectively.

Compared to conventional drip irrigation with NSAP treatment (CK), conventional drip irrigation with SAP (T5) and alternate drip irrigation with SAP (T1) treatments reduced leaf MDA content by 15.2 and 9.7%, respectively, but other treatments increased leaf MDA content by 19.2-101.0%. T1 increased root activity and the contents of leaf Chl and SS by 162.4, 38.0 and 8.5% but reduced leaf Pro content by 7.2%, indicating that T1 caused less accumulation of osmoregulation substances to provide better water environment for plant growth.

Physiological changes in plants can reflect degree of damage due to water stress (Foyer and Noctor, 2000; Wang *et al.*, 2012). Drought stress can suppress chlorophyll biosynthesis, increase chlorophyllase activity and accelerate chlorophyllase decomposition, so it reduces chlorophyll content significantly (Jiao *et al.*, 2010). In the study, leaf chlorophyll content in alternate drip irrigation was higher, which might be associated with the degree of water stress (Ceyda *et al.,* 2013), indicating that alternate drip irrigation can also improve light energy utilization of young *Coffea arabica* tree. Superabsorbent polymers can improve soil physical properties and water-holding capacity, and relieve drought stress and promote crop growth (Yazdani *et al.,* 2007). Yang *et al.* (2011) found slower root growth, aging and even death in no-watering side of fixed drip irrigation because of soil drought for a long time. In this study, Leaf SS, MDA and Pro contents in fixed drip irrigation with NSAP treatment were higher than those in conventional drip irrigation with SAP treatment, which was in agreement with previous the results of Zhang and Yin (2009). This is due to continuous soil drought in no-watering side of fixed drip irrigation, accumulation of osmotic substances can maintain cell expansion pressure and normal physiological metabolic activity when tissue water potential decreases, so as to prevent dehydration of cells and tissues, and improve water use efficiency (Akcay *et al.,* 2010). Compared to conventional drip irrigation with NSAP treatment (CK), alternate drip irrigation with SAP treatment (T1) had higher leaf chlorophyll content and root activity, but lower accumulation of osmotic substances, indicating that T1 could have vigorous root metabolism and provide better water environment for young *Coffea arabica* tree, which was beneficial for water absorption. The possible reason is that superabsorbent polymers can improve soil moisture and aeration, which partially compensate drought stress caused by alternate partial root-zone irrigation (Bai *et al.,* 2010). In addition, different zones of root system in alternate partial root-zone irrigation were subjected to certain degree of water stress, which may stimulate root absorption compensation function (Du *et al.,* 2008; Kang *et al.,* 2002).

Table 2 : Effect of drip irrigation method and super absorbent polymer on physiological parameters of young *Coffea arabica* tree

Drip irrigation method	Superabsorbent polymers level	Leaf water content(%)	Chlorophyll (mg g^{-1})	Proline (ìg g^{-1})	Malondialdehyde (nmol g^{-1})	Soluble sugar (%)	Root activity [ìg (g h)$^{-1}$]
ADI	SAP	75.72±1.14a	3.84±0.11a	9.46±1.58b	19.86±1.76cd	1.54±0.23b	188.51±25.25a
	NSAP	71.38±0.91ab	3.45±0.01ab	18.30±2.82b	26.21±0.67bc	3.35±0.73ab	141.49±12.87b
FDI	SAP	72.86±1.27ab	3.62±0.14ab	17.33±0.95b	26.75±0.59b	2.33±0.14bc	76.29±5.32cd
	NSAP	67.68±0.84b	3.32±0.07b	32.53±2.53a	44.20±0.63a	4.53±0.15a	45.54±10.34d
CDI	SAP	75.75±3.35a	2.95±0.07c	6.17±0.91b	18.65±0.92d	1.18±0.02c	96.99±4.73c
	NSAP	75.95±2.40a	2.78±0.02c	10.20±0.90b	21.99±3.43bcd	1.42±0.09c	71.86±15.67cd

ADI, FDI and CDI represent alternate drip irrigation, fixed drip irrigation and conventional drip irrigation. SAP and NSAP represent added superabsorbent polymers and no superabsorbent polymers, respectively. Values are means ± standard errors (n=4). Different letters in the same column indicate significant difference (P<0.05), the same as below

Table 3 : Effect of drip irrigation method and super absorbent polymer on the growth of young *Coffea arabica* tree

Drip irrigation method	Superabsorbent polymers level	Plant height (cm)	Stem diameter (mm)	Leaf area (m^2 plant^{-1})	Shoot length (cm)	Root-shoot ratio	Specific leaf area (m^2 kg^{-1})
ADI	SAP	53.07±0.97bc	8.93±0.06c	0.41±0.02bc	231.72±4.30b	0.61±0.05a	11.94±0.37a
	NSAP	49.53±0.29c	8.66±0.07c	0.36±0.01cd	202.70±1.85c	0.47±0.11b	12.28±0.53a
FDI	SAP	53.03±1.29bc	7.96±0.02d	0.35±0.01cd	205.88±10.65c	0.48±0.10b	12.31±0.57a
	NSAP	49.18±1.71c	7.81±0.06d	0.33±0.02d	197.26±3.19c	0.45±0.10b	12.71±0.46a
CDI	SAP	62.82±1.58a	10.12±0.04a	0.55±0.03a	280.79±4.58a	0.48±0.02b	12.60±0.46a
	NSAP	58.85±3.43ab	9.61±0.24b	0.44±0.01b	236.86±4.37b	0.38±0.05c	13.26±0.19a

Compared to conventional drip irrigation, alternate drip irrigation reduced plant height, stem diameter, leaf area and shoot length by 15.7, 10.9, 23.0 and 16.1%, and fixed drip irrigation by 16.0, 20.1, 31.1 and 22.1%, respectively, indicating that alternate drip irrigation and fixed drip irrigation inhibited the growth of young *Coffea arabica* tree (Table 3). Compared to NSAP, SAP increased plant height, leaf area and shoot length by 7.2, 15.7 and 12.8%, and did not affect stem diameter significantly, which was beneficial for the growth and development of young *Coffea arabica* tree. SAP also increased root-shoot ratio by 20.3%, which was beneficial for the absorption and utilization of soil water and nutrients. Shoot length in T1, alternate drip irrigation with NSAP (T2), fixed drip irrigation with SAP (T3), fixed drip irrigation with NSAP (T4) and T5 treatments was 0.98, 0.86, 0.87, 0.83 and 1.19 times of CK, respectively.

Compared to conventional drip irrigation, alternate drip irrigation reduced leaf, shoot and total dry masses by 18.0, 18.7 and 12.2%, and fixed drip irrigation by 28.8, 27.7 and 27.1%, respectively, and fixed drip irrigation also reduced root dry mass by 24.2% (Fig. 1). SAP respectively increased leaf, shoot, root and total dry masses by 20.1, 12.9, 42.4 and 24.9% when compared to NSAP. Compared to CK, T5 increased leaf dry mass by 31.0%, T1 did not increase leaf dry mass significantly, and other treatments reduced it by 12.3-21.9%. T5 and T1 increased total dry mass by 34.8 and 13.8%, respectively, but other treatments reduced it by 7.5-20.3%.

Compared to NSAP, SAP reduced the percentage of shoot dry mass to total dry mass, but increased the percentage of root dry mass to total dry mass (Fig. 1), showing that SAP could enhance the development of root system and coordinate root-shoot ratio.

In the present study, plant height, stem diameter, leaf area and shoot length in fixed drip irrigation and NSAP treatment was lower, because soil in drying side of fixed drip irrigation and NSAP treatment was relatively dry, which might lowered root growth and inhibited canopy growth (An *et al.,* 2011; Tesfaye *et al.,* 2016). Superabsorbent polymers promoted growth of young *Coffea arabica* tree obviously under different drip irrigation methods because superabsorbent polymers could increase soil water storage and alleviate water stress caused by PRI (El-Amir *et al.*, 1993; Han *et al.*, 2006). Compared to conventional drip irrigation, alternate drip irrigation increased root-shoot ratio by 25.4%, but fixed drip irrigation did not increase it significantly, which was in agreement with previous results (Mingo *et al.*, 2004; Shao *et al.*, 2008). Wei *et al.* (2007) reported that soil drying-wetting could stimulate root compensation and promote root growth. SAP also increased root-shoot ratio by 20.3%, which is in agreement with the previous study (Eneji *et al.,* 2013), because SAP can improve the ratio of soil, liquid and vapor and soil granular structure, increase soil water content, and change soil ecological environment of root growth (Huang *et al.,* 2002). Thus alternate drip irrigation and SAP treatment could stimulate the root growth and improve water use efficiency (Jiao *et al.*, 2010).

Compared to conventional drip irrigation, alternate drip irrigation and fixed drip irrigation reduced water consumption by 32.1 and 30.8% (Fig. 2A). SAP reduced water consumption by 6.0% when compared to NSAP, while compared to CK, T1 saved irrigation water by 34.4%.

Similarly, conventional drip irrigation, alternate drip irrigation and fixed drip irrigation increased water use efficiency by 29.9 and 6.4%, respectively (Fig. 2B). SAP increased water use efficiency by 33.0% when compared to NSAP. Compared to conventional drip irrigation, T1, T2, T3, T4 and T5 increased water use efficiency by 73.4, 31.1, 42.3, 7.3 and 34.5%, respectively.

In this study, compared to conventional drip irrigation, alternate drip irrigation reduced water consumption and total dry mass by 32.1% and 12.2%, respectively, thus increased water use efficiency by 29.9%, which coincided with the previous results (Loveys *et al.*, 2000), indicating that alternate drip irrigation had greater water-saving potential in the production of young *Coffea arabica* tree, because alternate drip irrigation could regulate

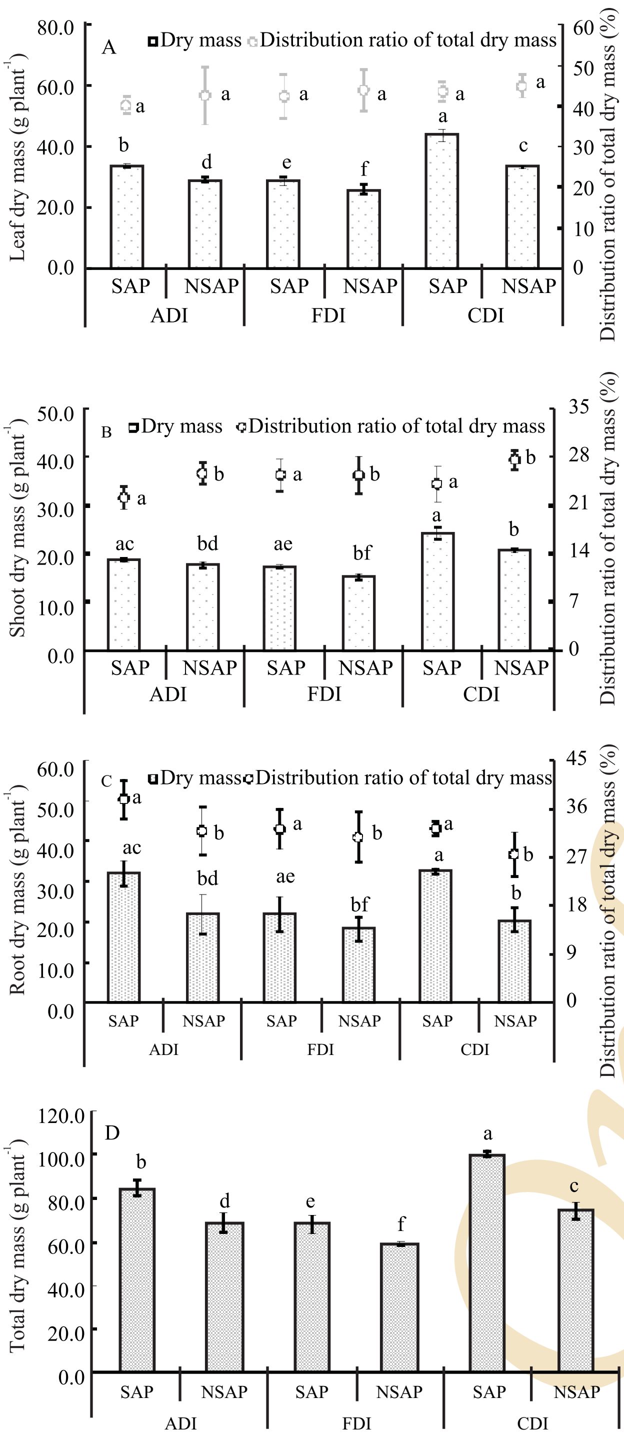

Fig. 1 : Effect of drip irrigation method and super absorbent polymer on the dry masses of leaf (A), shoot (B), root (C) and total(D)and their percentages of total dry mass in young *Coffea arabica* tree

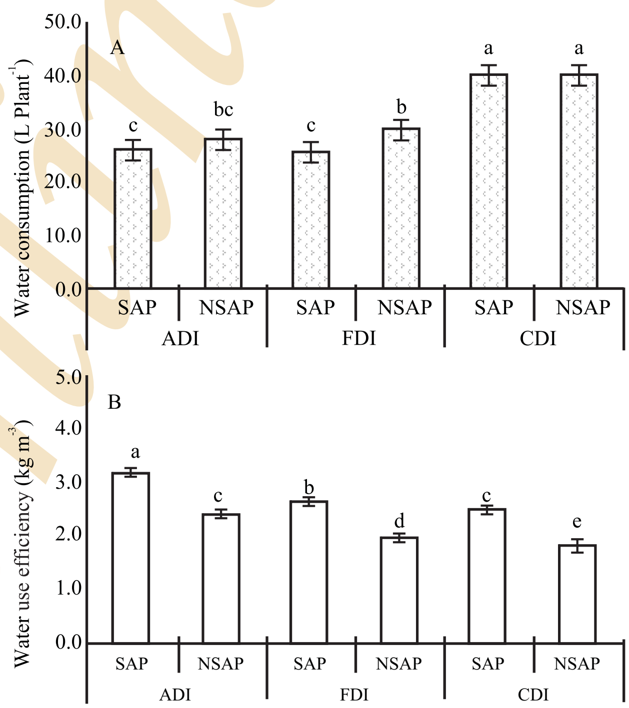

Fig. 2 : Effect of drip irrigation method and super absorbent polymer on water consumption (A) and water use efficiency (B) of young *Coffea arabica* tree

stomatal opening, reduce "luxury" transpiration and increase water use efficiency by stimulating plant root function and changing partial rootzone drying pattern (Kang *et al.*, 2002). Compared to conventional drip irrigation, fixed drip irrigation reduced total dry mass by 27.1%, but it did not increase water use efficiency significantly, because approximately half of the root system in fixed drip irrigation is exposed to drying soil, which affects growth of root and canopy, obviously (Kang *et al.*, 2002). SAP increased total dry mass and water use efficiency by 24.9 and 33.0%, respectively, which is in agreement with the previous study (Zhuang *et al.*, 2007). SAP significantly increased the ratio of shoot and root dry mass to total dry mass of young *Coffea arabica* tree, possible reason is that superabsorbent polymers can adjust matrix tightness, improve rhizosphere environment and coordinate root-shoot ratio (Eneji *et al.*, 2013). Compared to CK, T1 increased total dry mass and water use efficiency by 13.8 and 73.4%, respectively, because the combination of alternate drip irrigation and SAP could improve the abilities of root absorption and synthesis and promote growth, thus T1 had higher water-saving potential in young *Coffea arabica* tree.

Thus alternate drip irrigation with super absorbent polymers could promote the growth and water use efficiency of young *Coffea arabica* tree and was optimal irrigation management for young coffee tree.

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